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STRESS ANALYSIS OF AN OVERLOADED BREECH RING

P. C. T. Chen
Y. F. Cheng

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LARGE CALIBER WEAPON SYSTEMS LABORATORY
BENÉT WEAPONS LABORATORY
WATERVLIET, N. Y. 12189

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A two-dimensional model of the meridian section of a breech ring was made of a photoplastic material which had been calibrated optically and mechanically. The location and magnitude of the maximum fillet stress in an overloaded breech ring was determined experimentally and numerically. Residual stress resulting from elastic unloading was calculated. The comparison between numerical and experimental results is satisfactory.

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INTRODUCTION

In guns with a sliding block breech mechanism, breech ring life is typically limited by failures originating in the rear fillet near the block/ring contact region. There have been a considerable number of photoelastic studies made on weapon breeches of this type.[1-3] The observations indicate that high tensile stress produced by stress concentration at the fillet was responsible for the failure. Sometimes failure can be prevented by changing the geometry,[3] adding more weight and/or using higher strength materials. It is not always possible to increase the size or weight because of system considerations. Autofrettage has proved to be an efficient process in the design of gun barrels.[4] The elastic pressure capacity and the fatigue life can be increased. The technique is based on the production of beneficial stresses to counteract the high operating stresses induced by firing. This paper describes an exploratory study of the autofrettage of a breech ring. The residual stresses in an overloaded breech ring will be determined experimentally and numerically.

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[1] T. F. Maclaughlin, "Photoelastic Stress Analysis of Conventional and Serrated Slide Block Breech Designs," Watervliet Arsenal Technical Report WVT-6830, August 1968.

[2] G. P. O'Hara, "Photoelastic Stress Analysis of a High Pressure Breech," Watervliet Arsenal Technical Report WVT-7057, December 1970.

[3] Y. F. Cheng, "On Maximum Fillet Stresses in Breech Ring," Watervliet Arsenal Technical Report WVT-7255, October 1972.

[4] T. E. Davidson, A. N. Reiner, and D. P. Kendall, "A New Approach to the Autofrettage of High Strength Steel Cylinders," Experimental Mechanics, Vol. 2, No. 2, pp. 33-40, 1962.

The experimental approach is based on the photoplasticity method[5,6] and a two-dimensional model for a sliding breech mechanism was designed. The breech ring is made of polycarbonate resin which has been calibrated optically and mechanically. The numerical approach is based on the finite-element method[7] and a computer program for two-dimensional elastic-plastic problems is developed. An incremental loading procedure is used to determine the stresses in an overloaded breech ring. The location and magnitude of the maximum tensile stress as well as the residual stress after complete unloading are determined. The comparison between numerical and experimental results is satisfactory.

MATERIAL CALIBRATION

The breech ring is made of polycarbonate resin which was first suggested in 1962 for use as a photoplastic material.[8] It behaves as a ductile material and has good transparency under both elastic and plastic states. It has a Poisson's ratio of 0.38 in the elastic state and a limiting value of 0.5 in

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[5] M. M. Froct and R. A. Thomson, "Studies in Photoplasticity," Proceedings Third U.S. National Congress Applied Mechanics, pp. 533-540, 1958.

[6] M. M. Froct and Y. F. Cheng, "An Experimental Study of the Laws of Double Refraction in the Plastic State in Cellulose Nitrate - Foundations of Three-Dimensional Photoplasticity," International Symposium of Photoelasticity, pp. 195-216, 1961.

[7] Y. Yamada, N. Yoshimura, and T. Sakurai, "Plastic Stress-Strain Matrix and Its Application for the Solution of Elastic-Plastic Problems by the Finite Element Method," International Journal of Mechanical Science, Vol. 10, pp. 343-354, 1968.

[8] K. Ito, "New Model Materials for Photoelasticity and Photoplasticity," Experimental Mechanics, Vol. 2, No. 12, pp. 373-376, December 1962.

the plastic state.[9] It shows both optical and mechanical creeps (birefringence and strain) at stresses above 4000 psi.[9] It follows von Mises yield criterion with negligible error.[10] The material chosen for this investigation was manufactured by the General Electric Company and marketed under the trade name LEXAN.

A sheet of LEXAN 0.12 inch thickness was annealed at 300°F. Tensile calibration specimens were machined. Calibration tests were carried out at a temperature of 73° ± 3°F and a relative humidity of 35% ± 5%. (Photoplastic experiments are both temperature and relative humidity sensitive.) Tensile load was applied by means of dead weights. The gage length was 1.5 inches. A traveling telemicroscope was used to read the gage length under load. The strain was then calculated. Birefringence was determined by means of Senarmont's principle of compensation with a collimated monochromatic light source (5461 Å). During the calibration, Luder's lines have been observed confirming that the material follows the von Mises yield criterion.

Figures 1 and 2 show the fringe versus time and strain versus time curves at constant stress, respectively. It can be seen that the material creeps both optically and mechanically at a stress of above 4000 psi, confirming the previous findings. It can also be seen that the creep

[9] G. A. Gurtman, W. C. Jenkins and T. K. Tung, "Characterization of a Birefringent Material for Use in Photoelasticity," Douglas Report SM-47796, Missile and Space System Division, Douglas Aircraft Company, January 1965.

[10] J. K. Whitfield and C. W. Smith, "Characterization Studies of a Potential Photoelastoplastic Material," Experimental Mechanics, Vol. 12, No. 2, pp. 67-72, February 1972.

stabilizes after a time interval of 240 minutes. Consequently, model tests were made at the same temperature and relative humidity as were the calibration. Also, all data was taken at 240 minutes after loading.

The uniaxial stress-fringe and stress-strain curves for 240 minutes after loading were constructed from Figures 1 and 2 and shown in Figures 3 and 4. These curves show that this material has an elastic fringe value of 36 psi per inch, elastic modulus of 3.25×10^5 psi, and a proportional limit of approximately 6200 psi. The curved portion of the stress-strain (σ-ε) curve as shown in Figure 4 can also be described by the modified Ramberg-Osgood equation in the following form,[11]

$$E\varepsilon/\sigma_B = \sigma/\sigma_B + (3/7)(\sigma/\sigma_B)^n \quad \text{for} \quad \sigma_C \geq \sigma \geq \sigma_A \tag{1}$$

and the values of five parameters are

$$E = 325 \text{ ksi}, \quad n = 11.5, \quad \sigma_A = 6.2 \text{ ksi}, \quad \sigma_B = 8.7 \text{ ksi}, \quad \sigma_C = 9.576 \text{ ksi} \tag{2}$$

where n is a parameter, σ_B is the secant yield strength equal to the ordinate of the intersection with the stress-strain curve of a line through the origin having a slope equal to 0.7E, and σ_C is the flow stress at which the slope of the stress-strain curve is zero.

[11] W. Ramberg and W. R. Osgood, "Description of Stress-Strain Curves by Three Parameters," National Advisory Committee for Aeronautics, Technical Note No. 902, 1943.

EXPERIMENTAL APPROACH

Photoplastic Model

The experimental approach used is the photoplastic method which is based on the non-linear stress-optical law.[5,6] In particular, the maximum fillet stress is to be determined for an elastic load as well as an elastoplastic load.

A full scale, two-dimensional model of the meridian section of a breech ring was made of 0.12 inch thick LEXAN plate, as shown in Figure 5. The block was made of aluminum. In order to minimize any effect of material nonhomogeneity, the ring was cut closely to the calibration specimens and its line of loading was parallel with that of the calibration specimens. The top of the ring was fixed. The load was applied through a pin at the top of the block by means of dead weights. Guide plates were added to prevent buckling. Initially the block was in full contact with the ring. As load increased, the contact region changed and a gap was developed in the central portion. The width of central gap under the maximum test load of 1144 pounds was observed to be about five inches.

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[5] M. M. Froct and R. A. Thomson, "Studies in Photoplasticity," Proceedings Third U.S. National Congress Applied Mechanics, pp. 533-540. 1958.

[6] M. M. Froct and Y. F. Cheng, "An Experimental Study of the Laws of Double Refraction in the Plastic State in Cellulose Nitrate - Foundations of Three-Dimensional Photoplasticity," International Symposium of Photoelasticity, pp. 195-216, 1961.

Maximum Fillet Stress

In order to find the maximum fillet stress at elastic state, the fringe order at the fillet was closely watched during the loading. The loads corresponding to the first four fringes were recorded as 23, 51, 78, 104 pounds, respectively. This incremental load required to raise one fringe order was found and averaged to give a value of 27 pounds tension per fringe, which also corresponds to a fillet stress of 300 psi per 27 pounds of load. After the elastic stress was determined, the model was loaded to 1144 pounds and held for an interval of 240 minutes. During this interval, the maximum fringe order was recorded intermittently. At the end of 240 minutes, the maximum fringe at the fillet had an order of 43 and the maximum fillet stress was found to be 9300 psi. Making the usual assumption that unloading is an elastic process, we can calculate the residual stress after removing the full load of 1144 pounds. The result is 9300 - (1144/27) x 300 = - 3400 psi.

NUMERICAL APPROACH

Method and Program

The numerical approach used is the finite element method based on the incremental stress-strain matrix.[7] Following the procedure outlined in reference 7, we have developed a finite-element computer program for solving two-dimensional elastic-plastic problems. The axisymmetric case was used to

[7] Y. Yamada, N. Yoshimura, and T. Sakurai, "Plastic Stress-Strain Matrix and Its Application for the Solution of Elastic-Plastic Problems by the Finite Element Method," International Journal of Mechanical Science, Vol. 10, pp. 343-354, 1968.

analyze gun tube problems[12] and the plane-stress case is used in the present investigation. The formulation is based on the linear displacement function in a triangular element. Four triangular elements are used to construct a quadrilateral element. The material behavior is characterized by the von Mises yield criterion, Prandtl-Reuss flow equations and isotropic hardening rule. A piecewise linear representation for the effective stress-strain curve is used. The program is implemented on IBM 360 model 44. The overlay feature is utilized for reducing the core storage requirement. The load-increments can be prescribed or determined by scaling to cause at least one more element to become yielded. A tape may be used to store the final results for output plotting and also for restarting a program from a point of completion of a given loading sequence.

Model and Loading

A finite-element representation for one half of the breech ring is shown in Figure 6. The other half is not needed because of symmetry. There are 224 grid points and 189 quadrilateral elements in this model. The grids 1 to 8 are constrained in x-direction only while grids 217 to 224 are held fixed. The top portion of the breech ring is omitted because this is believed to have little effect on the maximum stress information near the lower fillet. In fact this belief has been confirmed by obtaining the elastic solution for another finite element model with 70 additional quadrilateral elements in the

[12] P. C. T. Chen, "Elastic-Plastic Solution of a Two-Dimensional Tube Problem by the Finite Element Method," Transactions of Nineteenth Conference of Army Mathematicians, ARO Report 73-3, pp. 763-784, 1973.

top portion. The difference between these two models for the maximum tensile stress is only 1.3 percent. The aluminum block is regarded as rigid and the load is transmitted to the ring through contact. Initially the block is in full contact with the ring. As the load increases, a gap develops in the central portion. The width of the central gap under the full test load was observed experimentally to be about five inches. Our elastic-plastic finite-element program in its present form cannot be used to determine the width of contact and the force distribution as functions of loading. Guided by the experimental information on the width of the central gap, we have chosen four contact conditions in this numerical investigation. The points of contact are at nodes (33, 41, 49, 57) for case 1, at nodes (41, 49, 57) for case 2, at nodes (49, 57, 65) for case 3 and at nodes (57, 65) for case 4. The width of contact and the force distribution in each case are assumed to remain unchanged during loading. The force distribution may be uniform or non-uniform and only the total force (2F) is allowed to increase. Uniform force distribution within the contact region is assumed in this study. Initially we apply a small force to obtain elastic solution and the total force (2F*) required to cause incipient plastic deformation is calculated by using Mises yield criterion. Then we apply the additional force in increments until the maximum test load is reached. The load increments we chose are non-uniform because our experience indicates that smaller increments should be used as plastic deformation becomes bigger. Our choice for the present investigation is to reduce the size of increments by one half in every ten steps. It is

important to choose a proper set of increments in order to obtain good results at reasonable cost. To reach the maximum test load of 2F = 1144 pounds, we used 11 increments for the four contact conditions and 22 increments for the second and third cases. The difference between 11 and 22 incremental loadings for the maximum tensile stress is found to be within 1 percent. The restart feature of the program has been used for the second contact condition to increase the total force from 1144 pounds to 1300 pounds in seven additional steps. The increments are again non-uniform.

Results and Discussions

The numerical results of the stresses in all elements were obtained for the overloaded breech ring under different contact conditions. Some of them are presented below in Figures 7-12. The major principal stresses in elements along the contact region and fillet are shown in Figures 7-10, for the four contact conditions. In each of these figures, we presented two sets of data corresponding to the load levels at the initial yielding (F*) and at the maximum test load (F = 572 pounds). The incipient plastic deformation first occurs in element 99 for the first two cases and in element 50 for the last two cases. The values of load level for the four cases are F* = 312.8, 321.9, 221.7, 169.2 pounds. The initial yielding is tensile in element 99 and compressive in element 50. It is interesting to find out that the location of the maximum tensile stress is in element 99 for all contact conditions and this location remains unchanged as the total force increases. Since this location is of sufficient distance away from the contact regions,

it seems to suggest that Saint Venant's principle can be applied to this problem in the elastic as well as plastic range of loading. The values of the maximum tensile stress based on the four contact conditions are 2029, 1972, 1939, 1936 psi at F = 100 pounds and 9532, 9361, 9174, 9119 psi at F = 572 pounds. It should be noted that the stresses in the finite element program were calculated at the centroid of each element but only one principal stress at the boundary was measured. The values of the maximum tensile stress at the fillet based on experimental approach are 2222 psi at F = 100 pounds and 9300 psi at F = 572 pounds. For the purpose of comparison, the boundary stress is determined by extrapolation using the calculated results for those elements along the radial direction through element 99. This is illustrated in Figure 11 for the second case of contact condition. Similar figures for the other three cases are not shown. Three curves are plotted in Figure 11 and they represent the major principal stresses for three load levels at the initial yielding, maximum test load and complete unloading after reaching the maximum load. The residual stresses after complete unloading are determined by assuming that unloading process is purely elastic. Our numerical results reveal no reverse yielding. In extrapolating the boundary stress, we shall remember that the maximum tensile stress shall not exceed the flow stress of 9576 psi. As seen in Figure 11, a comparison between the numerical and the experimental results for the maximum tensile stress indicates that a satisfactory agreement has been reached. In Figure 12, two principal stresses as well as the residual stresses in element 99 are shown as functions of loading. Only the second case of contact conditions is

presented here for illustration. The residual stress is determined by assuming a purely elastic unloading resulting from various stages of loading. The minor principal stress (σ_2) is found to be a nearly linear function of loading and its residual value is very small. The value of the principal stress angle for all contact conditions and for all load levels is found to lie within -26° to -27° with respect to the x-axis. As can be seen in Figure 12, the major principal (σ_1) and its residual value increase in magnitude as the total contact force increases but they are of opposite sign. Therefore as a result of overloading, favorable residual stress can be produced.

CONCLUSION

A photoelastoplastic investigation and a finite-element stress analysis have been conducted for an overloaded breech ring made of polycarbonate material. The location and magnitude for the maximum tensile stress have been determined for loading in the elastic as well as elastoplastic range. The favorable residual stress after unloading from various stages of loading has been calculated. A satisfactory agreement has been reached between the experimental and numerical results.

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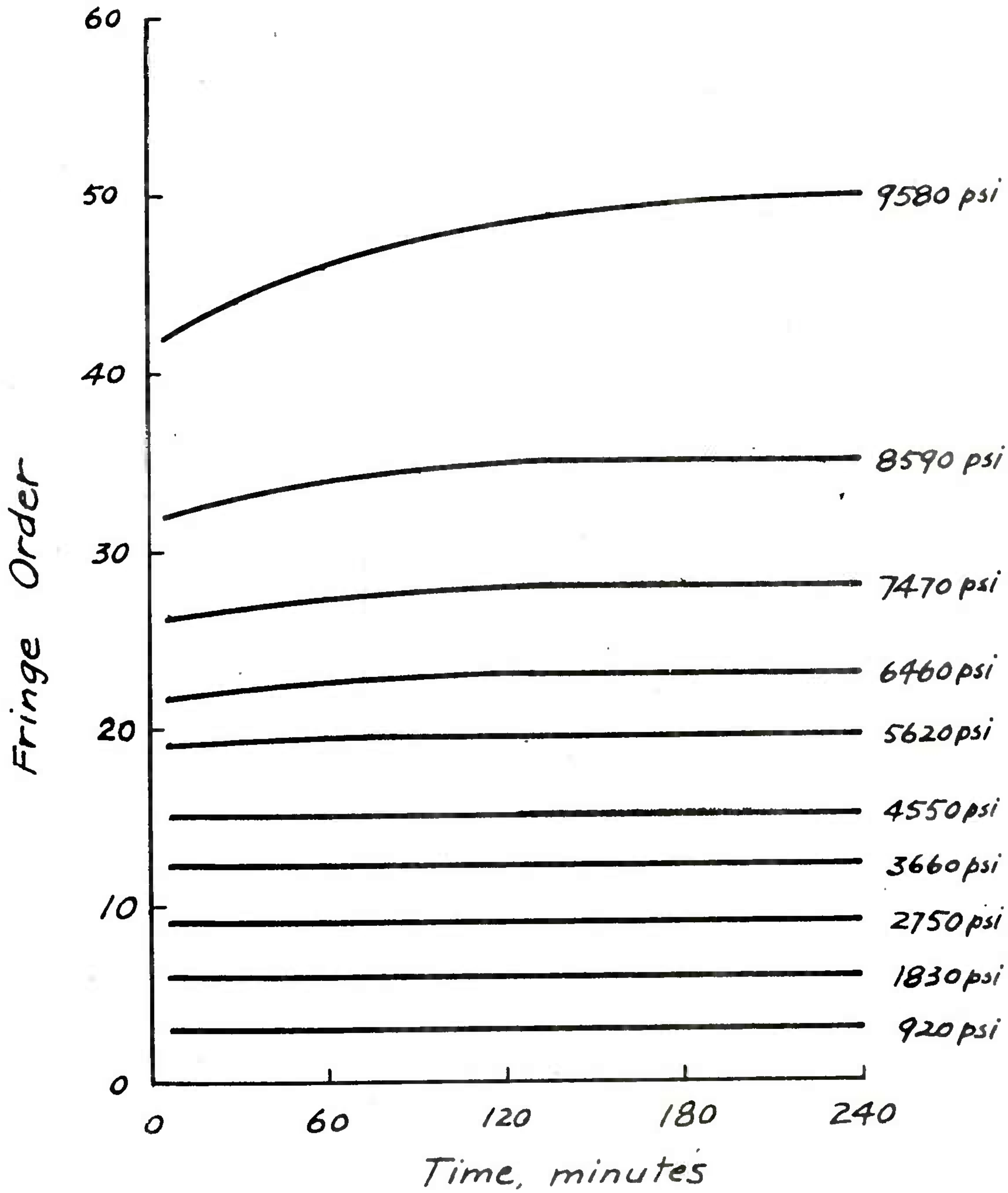


Figure 1. Birefringence at Constant Stress for LEXAN

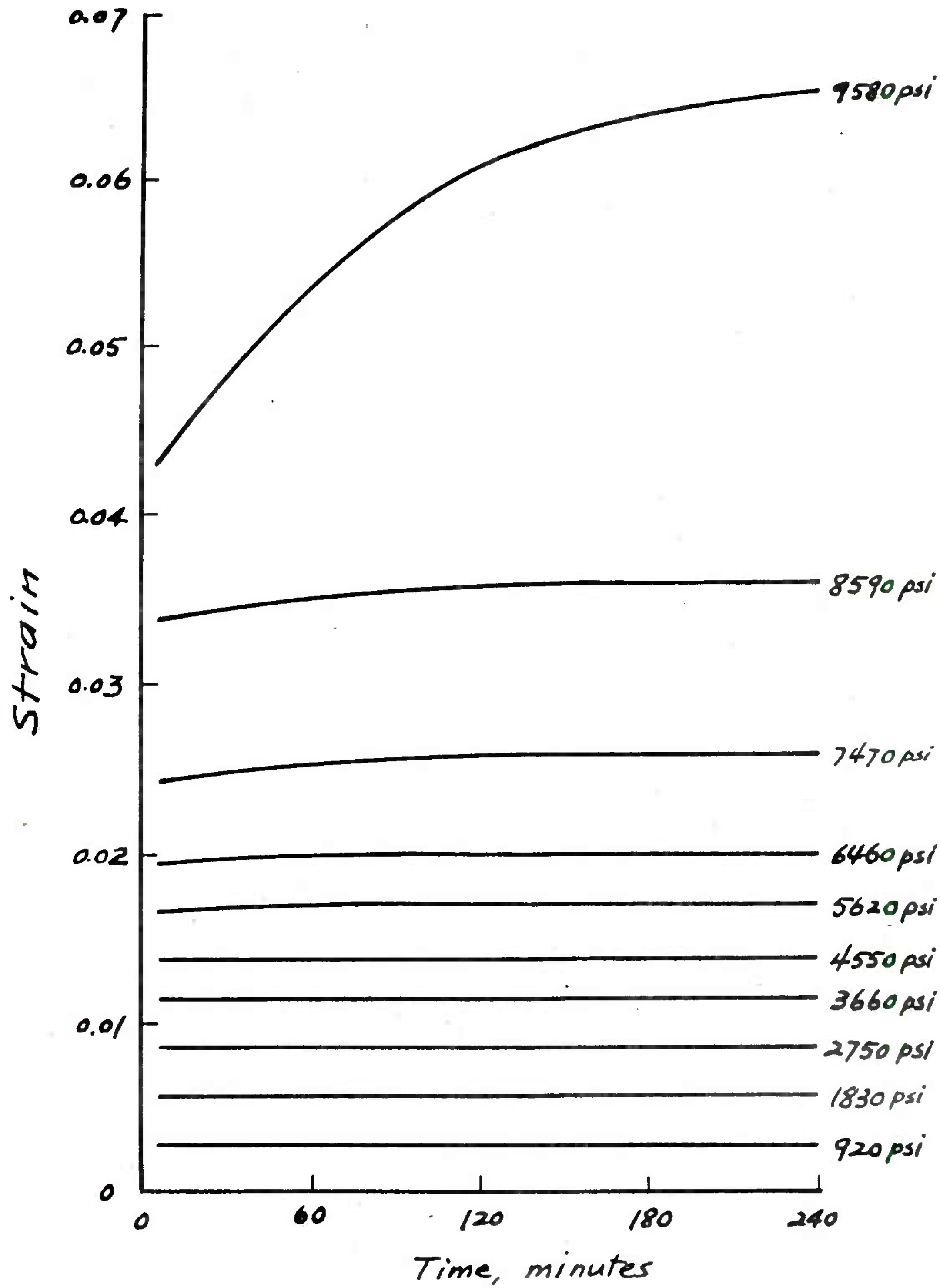


Figure 2. Strain at Constant Stress for LEXAN

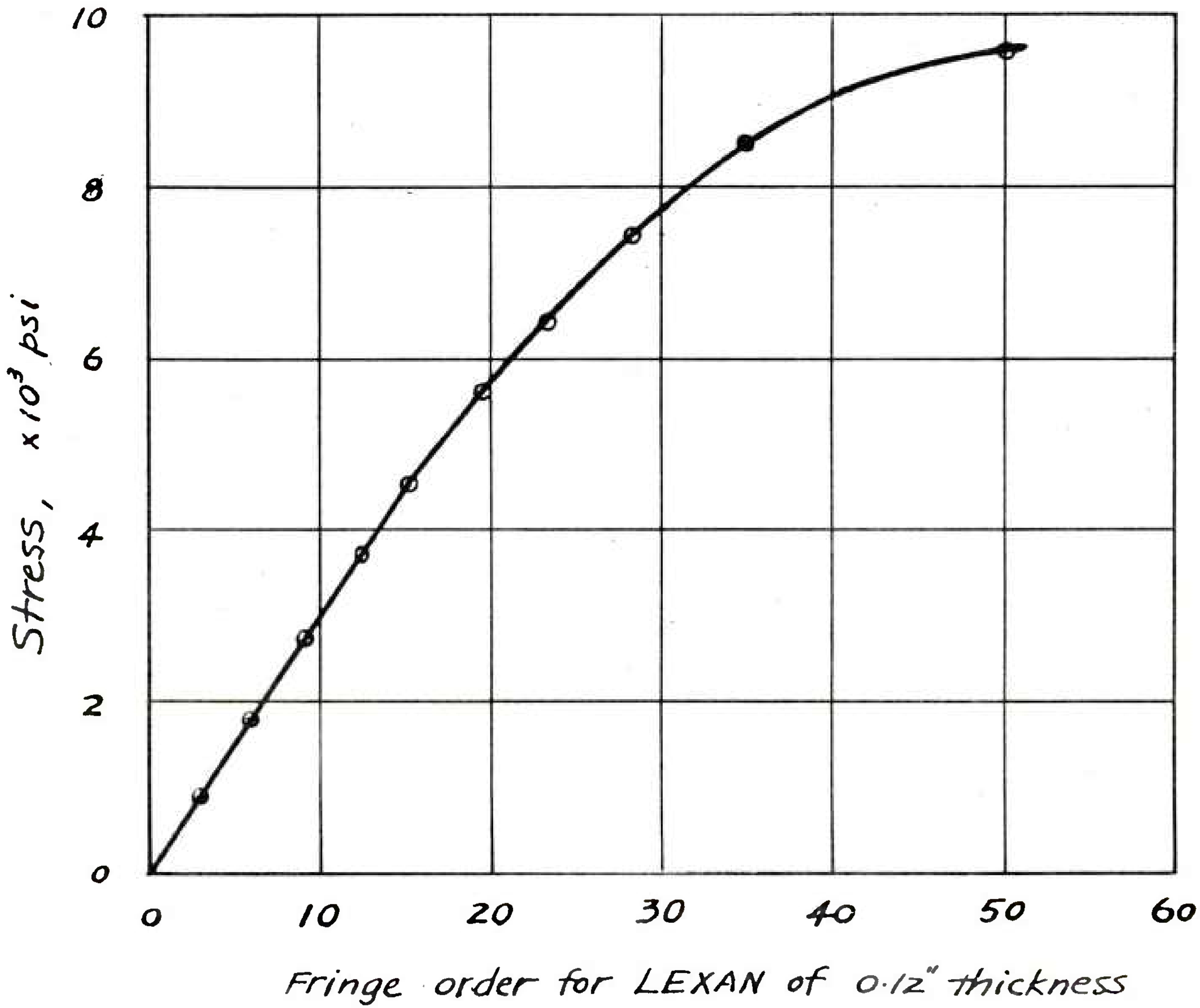


Figure 3. Stress-Fringe Curve for LEXAN

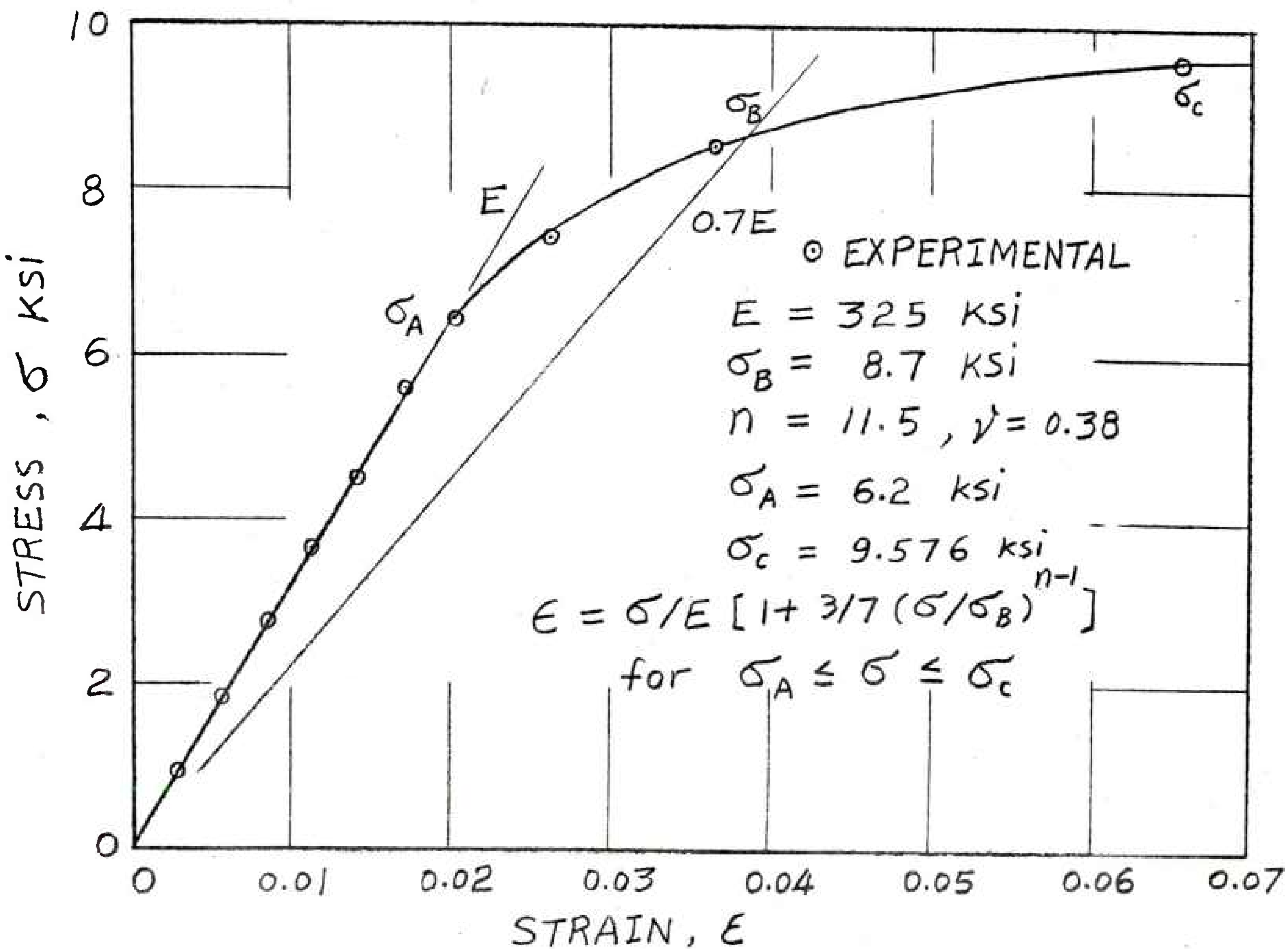


Figure 4. Stress-Strain Curve for LEXAN

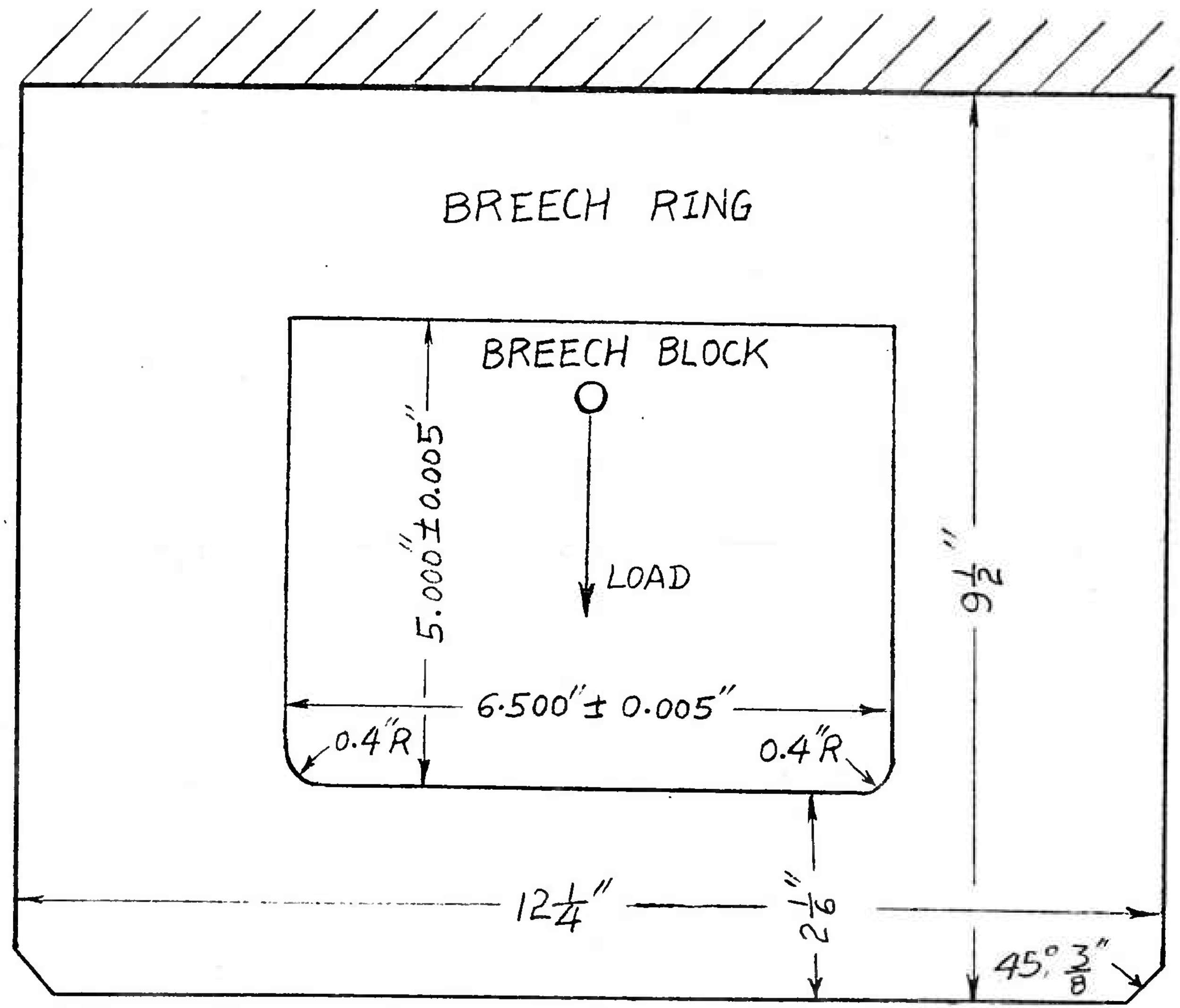


Figure 5. A Photoplastic Model for Breech Mechanism

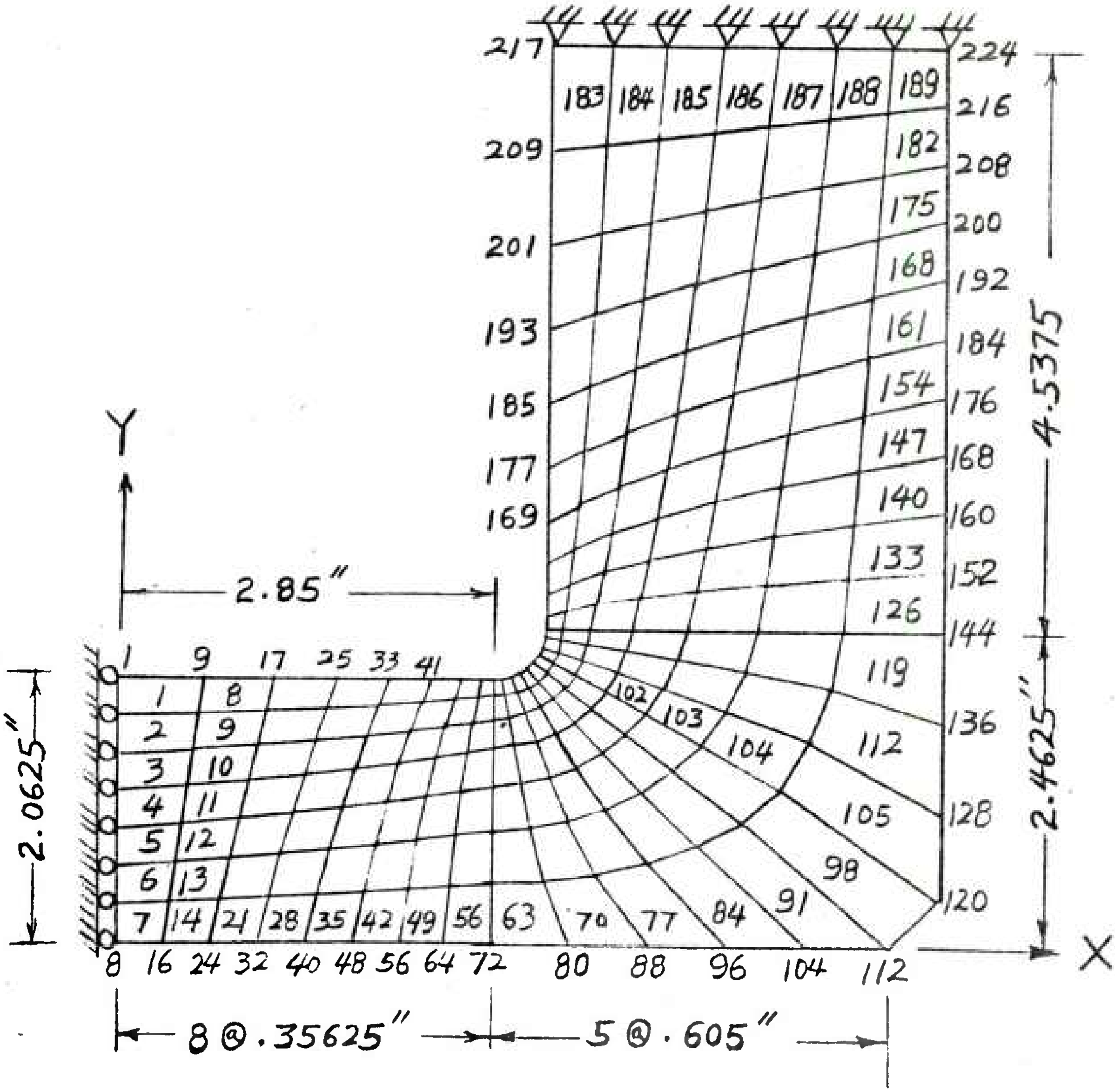
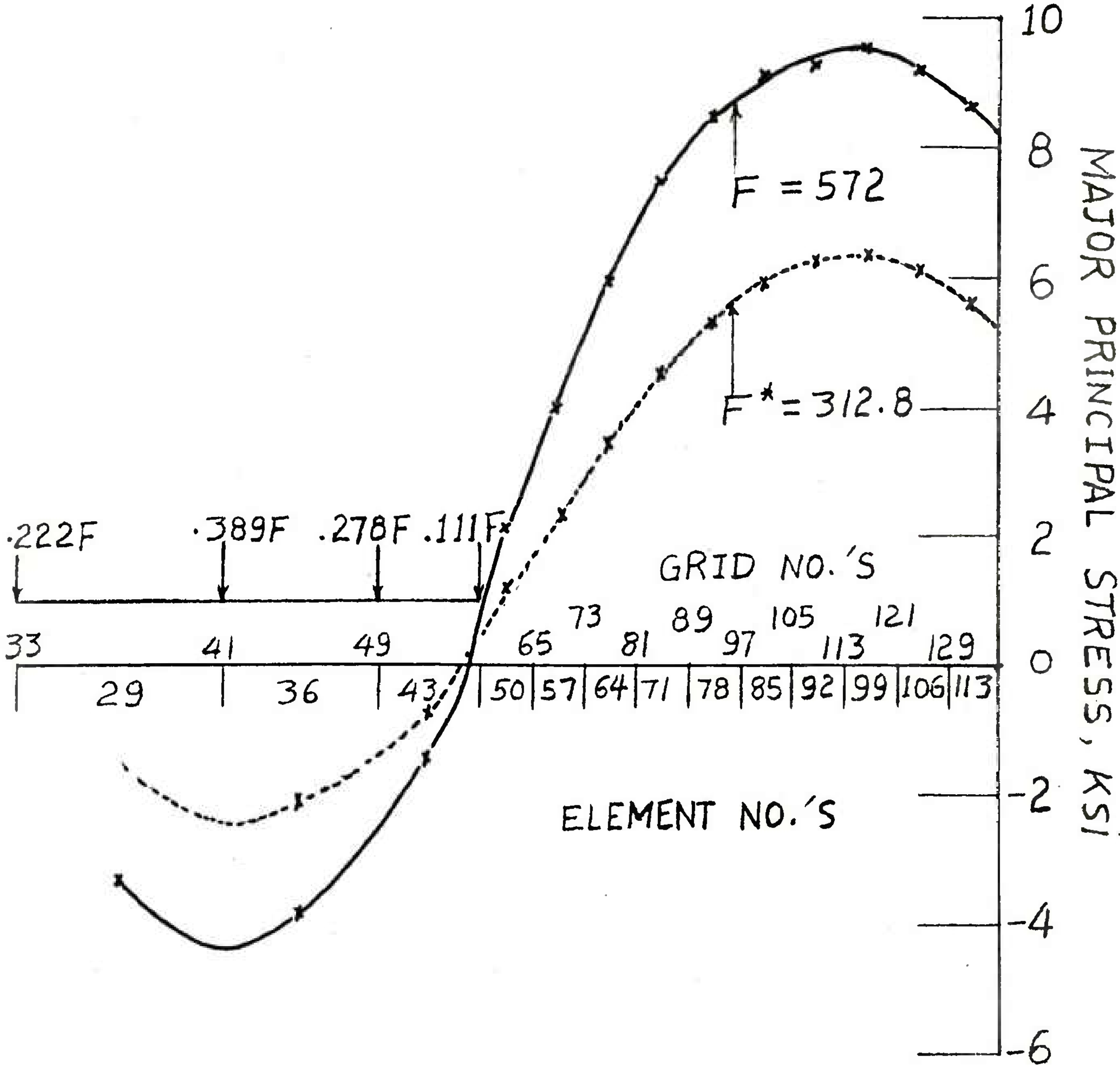


Figure 6. A Finite Element Model for Breech Ring



Fihure 7. Major Principal Stress Along the Boundary Elements for Case 1

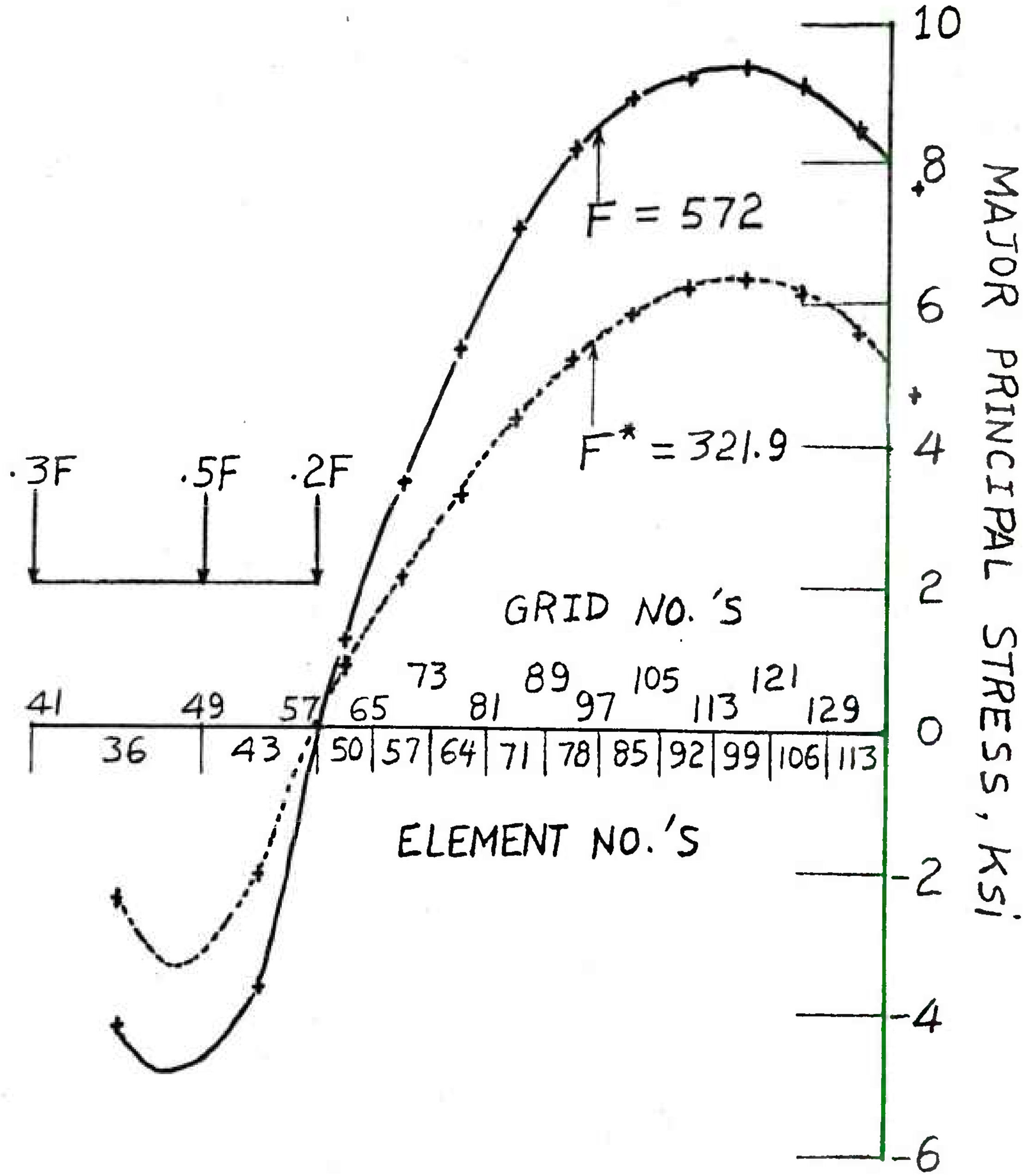


Figure 8. Major Principal Stress Along the Boundary Elements for Case 2

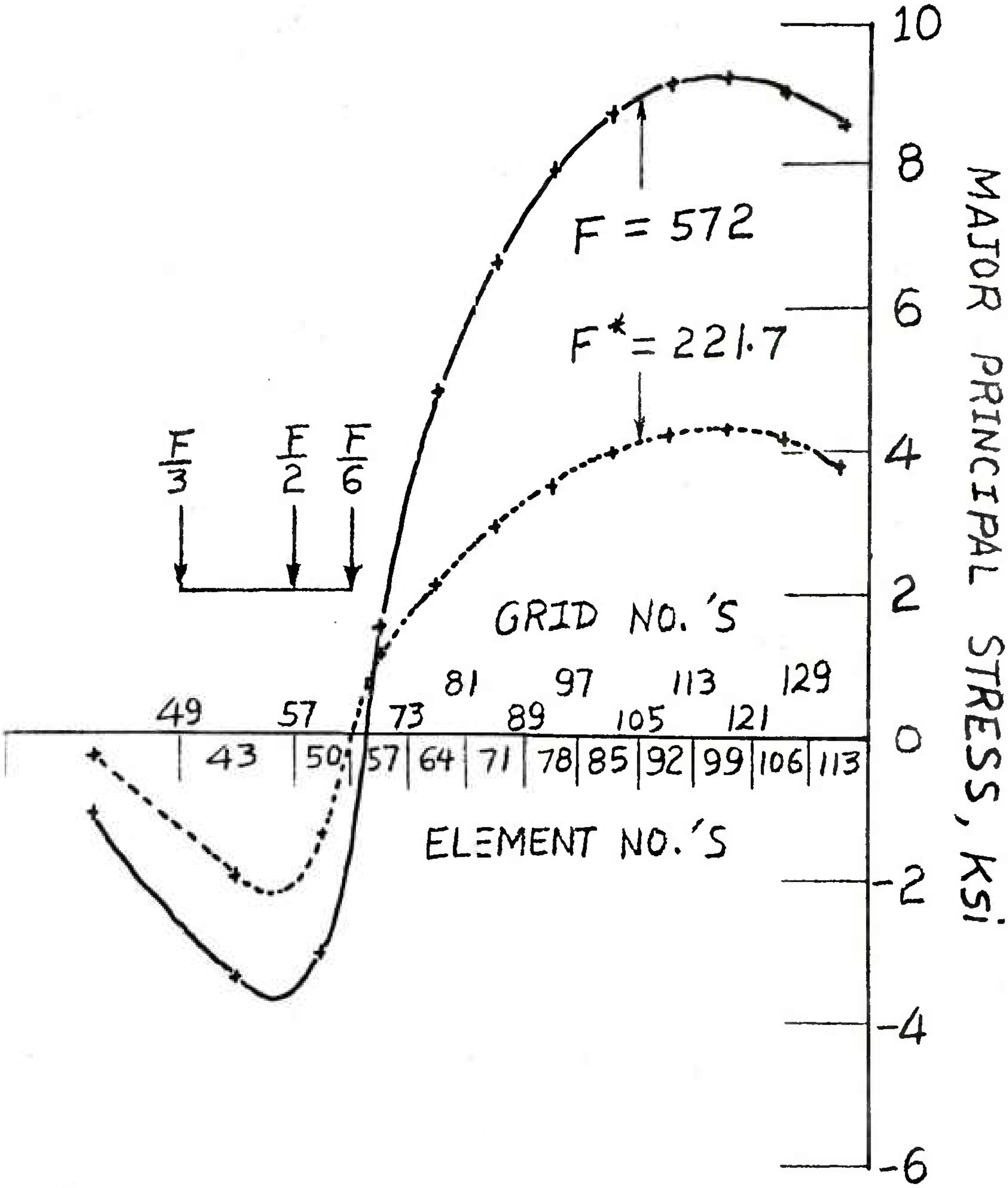


Figure 9. Major Principal Stress Along the Boundary Elements for Case 3

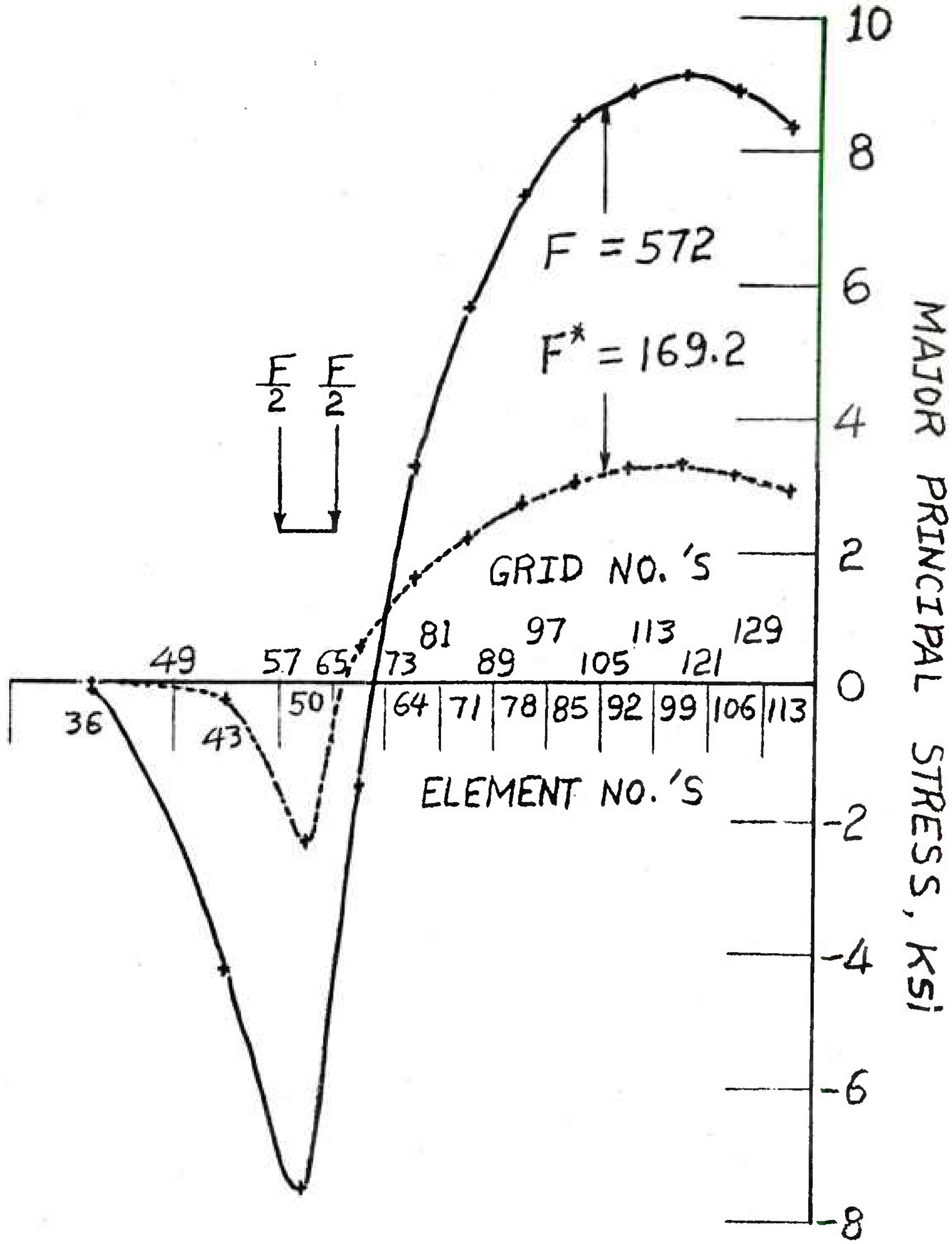


Figure 10. Major Principal Stress Along the Boundary Elements for Case 4

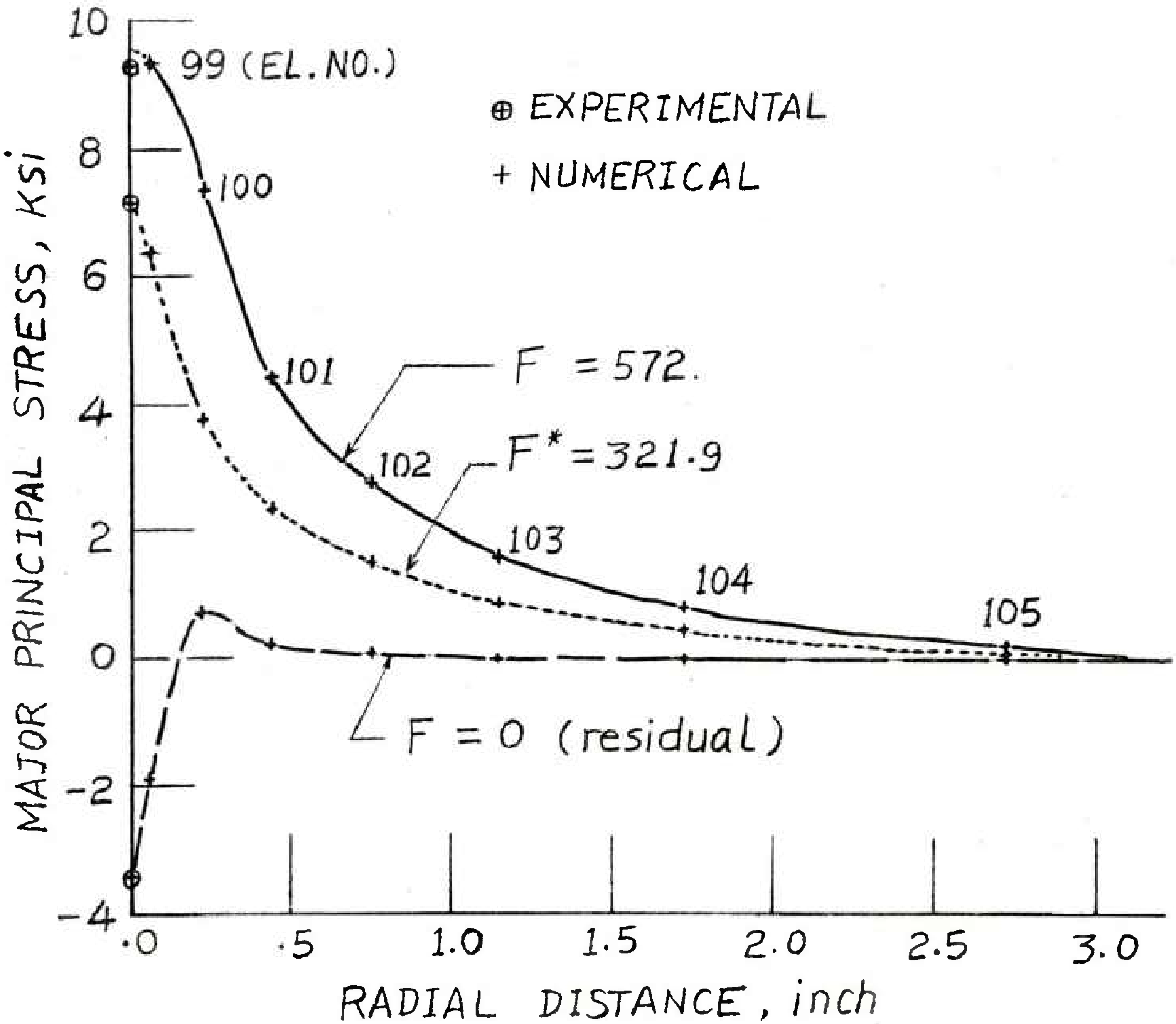


Figure 11. Determination of the Maximum Tensile Stress for Case 2

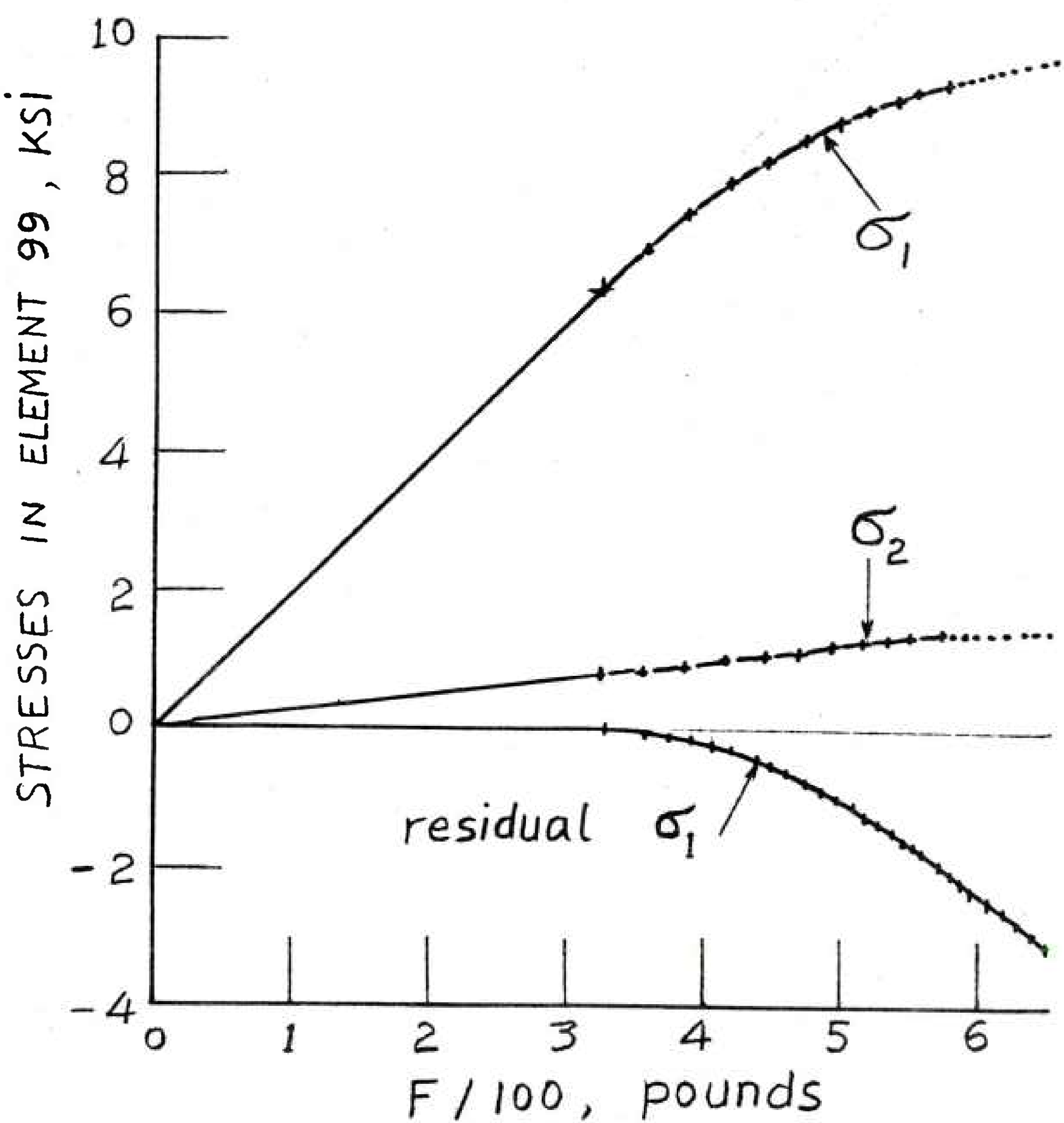


Figure 12. Stresses in Element 99 as functions of Contact Force for Case 2

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